First Order Estimate of the Contribution of Agriculture to Non-point Source Pollution in Three South African Catchments for Salinity, Nitrogen and Phosphorus

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ABSTRACT

This paper presents the findings of a study with the objective of making a first order estimate of the contribution that agriculture makes to non-point source (NPS) pollution in South African rivers. A bottom-up approach was used to calculate the mean monthly, seasonal and annual net Agricultural Non-point Source (ANPS) load for salinity, nitrogen and phosphorus in the Breede, Middle Vaal and Mgeni river catchments. The study found that reliable data on observed point source pollution loads and natural loads, was very limited and made it difficult to get a true estimate of the contribution of agriculture to NPS pollution. Despite the uncertainty that this introduced, the results of the study were sufficient to draw some initial conclusions. Agriculture, in its broadest sense, appeared to have a major impact on salinity loads, particularly in areas with a high degree of irrigation and natural saline geology. In general nutrient loads tended to be dominated by point sources rather than agriculture. It was also found that the net ANPS load was greatest during the wet season and in some cases there appeared to be a "first flush" impact at the start of the wet season.

Keywords: Agriculture, *Nitrogen, Non-point source pollution, Phosphorus, Salinity, South Africa.*

1 INTRODUCTION

1.1 Background

It is increasingly recognised that non-point source (NPS), or diffuse pollution plays a major role in the degradation of water quality; specifically with respect to salinity, eutrophication (nutrient enrichment), sediments, pathogens, pesticides and some heavy metals. It is furthermore, increasingly accepted that it is infeasible to properly manage water quality without addressing the contribution from non-point sources. Consequently, attention is increasingly devoted to the quantification of NPS pollution and to identify means to control it cost-effectively at source. Agriculture has both locally and internationally been implicated as a major source of NPS pollution because most of the land area is utilised for agricultural activities. It is therefore necessary to assess the contribution that the different agricultural activities make to the different manifestations of NPS pollution, to devise the means through which these can be controlled and to determine and predict the effect that control measures will have upon reducing NPS pollution. Understanding the production, delivery, transport and use components of agriculture-derived NPS loadings of water resources and being able to predict the fate of agriculture-related NPS constituents are discrete research themes in the agricultural water domain.

1.2 Aims and Objectives

In recognition of this, the Water Research Commission commissioned a one-year scoping study entitled "Modelling non-point source pollution in Agriculture from field to Catchment Scale: A Scoping Study". The objectives of this project were as follows:

General:

- To involve major players active in this field in a scoping exercise and knowledge gap analysis in order to develop the terms of reference for a longer term project that would establish an integrated model for the prediction of agricultural NPS pollution from field to catchment scales for the major agricultural NPS pollutants.

Specific:

- Produce a first order estimate of the contribution that agricultural activities are making towards NPS pollution
- Assess the level of understanding concerning the processes operating at various scales from the microscopic level up to catchment scale, for the main sources of agricultural NPS pollution
- Identify linkages between pollutants and processes that can mitigate or exacerbate the impacts
- Assess the range of mitigating measures that are available to address each of the major sources of agricultural NPS pollution, and
- Assess the predictive (modelling) ability that is available to address each of the major sources of agricultural NPS pollution.

This Report serves to present the findings in relation to the first of these specific objectives.

2 METHODOLOGY

2.1 Non-point Source Assessment Techniques

Pegram and Görgens (2001) presented a list of the most commonly used NPS models and analysis techniques. This list of methods can be separated into top-down and bottom-up approaches. The top-down approaches can be further sub-divided into empirical top-down approaches, such as pollution potential maps, unit area loading and potency factors, or modelling approaches.

The top-down approaches start with an assessment of the land-use type in a catchment and the loads that are put into the system from a variety of sources related to the land-use type. In the modelling methods, the fractions of the pollution loads that comes out of the system in each way are calculated by attempting to understand and model the mechanisms that lead to pollution loading. The empirical top-down approach uses, for example, export coefficients derived from observations of the concentration of various pollutants in the run-off from an area dominated by a particular land-use type. These export coefficients are calculated in terms of unit area load which can then be applied to other areas with the same land-use type. The bottom-up approach on the other hand, such as the statistical techniques, starts with an observation of what comes out of the system in the form of pollution loads measured in the receiving water resource and then works backwards to assign fractions of this load to potential sources including both natural and man-made sources. The assigned loads can then be compared with empirically determined unit area loading for the various types of land-use in order to validate the method. Hoffmann (1995), for example, used a bottom-up approach to measure non-point source pollution in the Hennops River Valley.

For the purposes of the First Order Estimate, it was decided to make use of a bottom-up approach based on observed values. This decision was based on the assumption that South Africa has a reasonably extensive database of water quality measurements taken both at selected sites on the major river systems and at major sites of point source pollution, such as the discharges from wastewater treatment works. It was also felt that this approach would be quicker and easier at getting a First Order Estimate of the importance of agriculture in non-point source pollution before embarking on a more detailed modelling exercise.

2.2 Selection of Catchments and Time Period

The Breede, Middle Vaal and Mgeni catchments were selected as a representative sample of different agricultural practices in South Africa. Individual sub-catchments were identified within these catchments based on the location of water quality sampling sites and the degree of agricultural activity. The distribution of suitable monitoring sites within a catchment meant that the First Order Estimate would have to be done at a relatively course scale with no sub-catchment being at a level of detail greater than quaternary catchment scale and some sub-catchments comprising as many as nine quaternary catchments. The individual sub-catchments are listed in **Table 1** along with the dominant crop type and the percentage of total agricultural area that is irrigated.

Table 1: Selected Sub-catchments

Study Sub-catchments		Percentage Irrigation (%)	Dominant Crop Type
Breede	Ceres	66	Stone Fruits
	Hex	85	Table Grapes
	Kogmanskloof	52	Vineyards/ Stone Fruit
	Poesjenels	83	
	Vink	65	
	Riviersonderend	6	Dry Land Wheat
Middle Vaal	Koppies	0.5	Maize/wheat /livestock
	Rhenoster	3	
	Vals	0.3	
	Allermanskraal	0.1	
	Erfenis	0.1	
	Vet	2	
Mgeni	Henley	0	Subsistence/ Livestock
	New H'over	0	Sugar
	Karkloof	0	Maize/ livestock
	Lions	35	Livestock
	Mpendle	24	Livestock
	Nagle	0	Sugar/ subsistence

The study period was initially set for hydrological years 1990 to 1999, so as to be closely related to the land-use data from the Centre for Scientific and Industrial Research (CSIR) National Land Cover Database (NLCD), which has its base year in 1995. This study period, however had to be reduced to a five-year period from 1990 to 1995, after it was found that there were no updated records of certain variables after 1995.

2.3 Selection of Water Quality Variables

The major contributions to non-point source pollution from agricultural lands are stream flow reduction, increased salinity, increased erosion, sediment yield, pesticides and nutrient yield from crop lands, associated with disturbed soil and applied fertilizers. For the purposes of the First Order Estimate, the following water quality constituents were considered due to the fact that these represent some of the key impacts of agriculture on surface water resources:

- Salinity – as measured in terms of Total Dissolved Solids (TDS)
- Inorganic Nitrogen - as the sum of Nitrite (NO_2^-), Nitrate (NO_3^-) and Ammonia (NH_4^+ and NH_3)
- Inorganic Phosphorus – as measured in terms of Orthophosphate (PO_4^{-3})

2.4 Observed Pollutant Loads

Average daily flow records for all the relevant gauges were obtained from the Department of Water Affairs and Forestry's (DWAF) electronic database for the period 1990 to 1999. Water quality samples for the same stations were also obtained from DWAF's electronic database for the same ten-year period. At best, these samples were taken at weekly intervals and in order to obtain a better estimate of the average monthly load, these weekly samples were infilled using FLUX. FLUX is based on the estimation of regression relationships between instantaneous concentration and daily streamflow observations that are used to infill the missing daily concentration data, based on the observed daily flows (Walker, 1987).

2.5 Natural Background Loads

Natural background loads were estimated based on the observed concentrations at "least impacted" reference sites in each catchment. The reference sites used were based on the sites identified by Malan and Day (2002) as least impacted sites in terms of discharge and water quality. Joubert and Hurley (1994) identified 352 DWAF gauging sites within South Africa that exhibited relatively natural discharge patterns. These gauges were screened by Malan and Day according to the criteria of Day, Dallas and Wachernagel (1998) to exclude the sites that were heavily polluted in terms of electrical conductivity, combined nitrate and nitrite and soluble phosphate levels. Rather than using the mean concentration values given by Malan and Day for these reference gauges, average monthly loads and flow volumes were calculated by infilling the grab samples using FLUX as described above. These were used to determine twelve average monthly concentrations and the reference site with the lowest concentration in each catchment was used to provide an estimate of the natural monthly background concentration. A summary of the average natural background load concentrations used are given in **Table 2**. Note that some of the sub-catchments in the Breede Catchment are known to have very high salinity loads due to their underlying geology. For this reason the background load for these sub-catchments was increased in accordance with the findings of Greef (1990).

Table 2: Natural Background Concentrations

Catchment	Gauge	TDS (mg/l)	NO^{-2}/NO^{-3} (mg/l)	PO_4^{-3} (mg/l)	NH_4^+ (mg/l)
Breede (1)	H2H005	22.80	0.0283	0.0163	0.0308
Breede (2)	Derived (4)	474.00	0.0730	0.0163	0.0308
Middle Vaal	C2H026	54.52	0.057	0.031	0.0400
Mgeni	U2H013	31.56	0.282	0.005	0.048

(1) Hex, Ceres, Riviersonderend, (3) Kogmanskloof, Poesjenels, Vink (4) Based on Greef (1990)

Water quality data on the major point sources in South Africa is supposed to be kept on DWAF's Pollution Monitoring (POLMON) system. This is a regionally based database that has been operational since 1989, with data on permit flows and water quality records for users who abstract raw water and return treated effluent to rivers. Not only are permit values indicated on the POLMON system, but also compliance of permit values should be tested at least once a month and indicated on the database. The POLMON system is currently being incorporated into the centralised Water Management System (WMS), but when it came to requesting data from the system it was found to be in a very poor state. No information on point source pollution loads could be obtained from two of the three catchments (Umgeni and Middle Vaal) and the information had to be obtained either from the original records of the water samples (Middle Vaal), which were themselves incomplete, or from Umgeni Water (Umgeni) which had reasonable records of water quality samples but no record of volumes of return flows. Even the data available for the Breede was incomplete: either with large periods of missing data or no records of certain water quality variables such as phosphates and nitrates.

Despite being predominantly agricultural, each catchment had a small percentage of urban land use. The pollutant exports from these areas tends to be higher than for agricultural and undisturbed land due to higher run-off coefficients with increasing impervious area and higher pollutant application rates. The unit export pollution loads from urban areas used in this study were derived from a study of non-point source pollution in the Hennops River Valley (Hoffmann, 1995) where pollution loads were calculated for a formal settlement and informal settlement and an Industrial and Commercial area, as well as a study by Novotny (1992) on pollution loads from American cities, and a study by Simpson *et al.* (1980) for Pinetown in Natal. The urban export pollution loads used for the First Order Estimate are summarised in **Table 3**.

Table 3: Urban NPS Unit Export Pollution Loads Used

Pollution Constituent	Commercial (kg/ha/a)	Industrial (kg/ha/a)	Residential (kg/ha/a)
TDS	125	125	185
Total Nitrogen	7.5	7.8	3.9
Ammonia	5.6	5.8	2.9
Nitrate/Nitrite	1.9	2.0	1.0
Orthophosphate	0.28	0.21	0.13

The monthly urban pollution load in each sub-catchment was estimated by multiplying the above unit export loads by the area of different types of urban land-use as recorded in the National Land Cover Database. This gave a mean annual urban load, which was then disaggregated to monthly loads dependent on the disaggregation of monthly incremental run-off from the sub-catchment.

2.6 Calculating the Net Agricultural NPS Load

A mass balance approach was used to determine the net Agricultural non-point source (ANPS) load. The net ANPS load is the incremental load coming off a sub-catchment after as many non-agricultural pollution sources have been accounted for. This is still a very broad category that includes irrigated and dry land agriculture, livestock farming, forestry and a number of unknown sources which could include increased load from rural settlements, transport infrastructure in the rural area, atmospheric deposition from nearby factories or power stations, fish farms, or other activities influencing stream flow and/or water quality.

In addition, the net ANPS load is the total change in load due to agriculture i.e. the difference between water abstracted for irrigation purposes and the sum of the irrigation return flows and the rainfall run-off. In many highly irrigated catchments with low rainfall this would lead to a negative volume as only a small fraction of the irrigated water returns to the stream, and in a perfectly balanced system this would be zero. The ‘lost” water is used by the plants or returns to the atmosphere through evapotranspiration. The salt and nutrient load, however, is not “lost” to evapotranspiration and is therefore either used by the plants or returns to the river in the return flows. One would therefore expect the net ANPS salinity loads to be positive, as salts are not generally used by crops and so all salt load applied to the crops will eventually return to the river plus any additional load due to agricultural practices. The net ANPS nutrient load, on the other hand, may be positive or negative depending on the amount of nutrients used by the crop and the availability of other sources of nutrients such as those from fertilizers.

Figure 1: Method Used to Calculate the net Agricultural NPS load

ANPS (load) = CY(load) – PS (load) – BNPS(load) – UNPS(load)

CY (load) = (DS(load) + AS(load) + EX(load)) - (US(load) + IM(load))
CY (vol.) = (DS(vol.) + AS(vol.) + EX(vol.)) - (US(vol.) + IM(vol.))
CR(vol.) = CY(vol.) - PS(vol.)
BNPS(load) = CR(vol.) x BNPS(conc.)
UNPS(load) = UNPS(kg/ha/a) x Urban area (ha)

CY = Catchment Yield	CR = Catchment Run-off
US = Upstream Gauge	DS = Downstream Gauge
EX = Exports	IM = Imports
PS = Point Source	BNPS = Background NPS
UNPS = Urban NPS	ANPS = Net Agricultural NPS

AS = Major non-agricultural abstractions
(vol.) = volume (Mm^3)
(load) = load (t or kg)
(conc.) = concentration (mg/*l*)

The method used to calculate the net ANPS load is shown in **Figure 1** and is described below. The first step in calculating the net ANPS load is to calculate the net incremental catchment yield (CY) in terms of both volume of water and pollution load. This is the difference between the flow volume and load observed at the downstream gauge (DS) and that observed at the upstream gauge (US), less any imported water (IM) and plus any major non-agricultural abstractions (AS) or exports (EX) from the mainstream between the gauges. The total net incremental catchment run-off (CR) is calculated by subtracting any point source return flow (PS) from the catchment yield flow volume. This incremental catchment run-off (CR) is then used to calculate the background non-point source pollution load (BNPS) by multiplying the catchment run-off (CR) by the estimated background concentration. The total incremental catchment run-off is used as it is assumed that the run-off from urban, agricultural and undisturbed areas will have the same level of naturally occurring salt and nutrient load. The additional urban non-point source pollution load (UNPS) is estimated by multiplying the urban area in the sub-catchment by the estimated unit area loading function. The net ANPS load is calculated by subtracting the background (BNPS), urban (UNPS) and point source (PS) loads from the catchment yield (CY) load, i.e. the difference between the observed upstream (US) and downstream loads (DS) less the impact of abstractions (AS), imports (IM) and exports (EX). An example of the calculation of the mean annual net ANPS for each of the selected water quality variables for the Riversonderend sub-catchment in the Breede Catchment is shown in **Figure 2.**

This mean annual net ANPS load was then divided by the total agricultural area in the sub-catchment to get an estimated net ANPS unit area load (in kg/ha/a). To account for climatic differences between sub-catchments, the net ANPS unit load was then normalised by the mean annual precipitation in the sub-catchment (in m) to give a net ANPS unit rainfall load (in kg/ha/m/a). This was done to facilitate the comparison of the net ANPS impact across catchments and sub-catchments in an attempt to establish links between the agricultural activities and net ANPS load.

Figure 2: Calculation of the Mean Annual net ANPS Load: Riviersonderend sub-catchment

Pollution Source	**Volume (Mm^3)**	**TDS (t/a)**	**NO_2^-/NO_3^- (kg/a)**	**PO_4^{-3} (kg/a)**	**NH_3/NH_4^+ (kg/a)**
Upstream Gauge: H6H012 (US)	121.35	6884	19486	2050	5867
Downstream Gauge: H6H009 (DS)	234.54	36492	53315	4438	7162
Export 1: Ruensveld-East (EX)	0.76	144	172	14	23
Export 2: Uensveld-West (EX)	0.15	13	22	3	7
Major Abstraction: Riv'end (AS)	0.32	28	47	5	15
Incremental Sub-catchment load (CY)	114.42	29794	34070	2410	1340
Point Source: Helderstroom Prison (PS)	0.1	28	158	433	1073
Catchment Run-off (CR)	114.32				
Background Load (BNPS)		10035	2417	1089	3510
Estimated Urban Load (UNPS)		90	487	63	1412
Mean annual net ANPS Load		19639	31008	823	-4655

3 RESULTS

For the purpose of comparison between sub-catchments, catchments and agricultural practices, a number of summary results tables are shown below. These tables summarise the mean annual net ANPS load, the unit area load and the unit rainfall load for each sub-catchment in terms of salinity (**Table 4**), total nitrogen (**Table 5**) and phosphate (**Table 6)** loads. The loads given are the annual mean for October 1990 to September 1995.

Table 4: Net ANPS Salinity Loads

Sub-catchments		**Mean annual net ANPS Load (t/a)**	**Net ANPS Unit Area Load (kg/ha/a)**	**Net ANPS Unit Rainfall Load (kg/ha/m/a)**
Breede	Ceres	9061	448	884
	Hex	5802	612	1219
	Kog'kloof	20415	1183	2323
	Poesjenels	445	1293	2549
	Vink	2124	957	1870
	Rivier'end	19640	262	525
Middle Vaal	Koppies	4268	68	110
	Rhenoster	286	2	3
	Vals	8467	26	47
	All'kraal	6379	42	70
	Erfenis	7860	59	100
	Vet	28217	71	140
Mgeni	Henley	269	34	36
	New H'over	736	22	22
	Karkloof	239	16	15
	Lions	620	45	45
	Mpendle	0	0	0
	Nagle	1755	89	100

Table 5: Net ANPS Nitrogen Loads

Sub-catchments		Mean annual net ANPS Load (t/a)	Net ANPS Unit Area Load (kg/ha/a)	Net ANPS Unit Rainfall Load (kg/ha/m/a)
Breede	Ceres	41	2.05	4.04
	Hex	73	7.72	15.39
	Kog'kloof	53	0.31	60.60
	Poesjenels	2	0.59	1.17
	Vink	1	0.63	1.24
	Rivier'end	26	0.35	0.70
Middle Vaal	Koppies	346	0.01	0.01
	Rhenoster	-493	0.00	-0.01
	Vals	-101943	-0.32	-0.57
	All'kraal	-6195	-0.04	-0.07
	Erfenis	13805	0.10	0.18
	Vet	-96772	-0.24	-0.48
Mgeni	Henley	8925	1.13	1.20
	New H'over	4928	0.15	0.15
	Karkloof	3592	0.24	0.23
	Lions	3086	0.22	0.22
	Mpendle	0	0.00	0.00
	Nagle	-4924	-0.25	-0.28

Table 6: Net ANPS Phosphate Loads for the Breede Catchment

Sub-catchments		Mean annual net ANPS Load (t/a)	Net ANPS Unit Area Load (kg/ha/a)	Net ANPS Unit Rainfall Load (kg/ha/m/a)
Breede	Ceres	-2.44	-0.12	-0.24
	Hex	-0.13	-0.01	-0.03
	Kog'kloof	0.12	0.01	0.01
	Poesjenels	0.07	0.02	0.04
	Vink	0.02	0.01	0.02
	Rivier'end	0.82	0.01	0.02
Middle Vaal	Koppies	-2.90	-.05	-0.08
	Rhenoster	0.88	0.01	0.01
	Vals	-24.85	-0.08	-0.14
	All'kraal	-6.18	-0.04	-0.07
	Erfenis	1.14	0.01	0.02
	Vet	-43.59	-0.11	-0.22
Mgeni	Henley	-0.75	-0.10	-10.13
	New H'over	-0.71	-0.02	-2.18
	Karkloof	0.14	0.01	0.88
	Lions	0.29	0.02	2.11
	Mpendle	0	0	0
	Nagle	2.27	0.12	12.87

4 DISCUSSION

It is immediately clear from the results that there are a number of cases in which negative loads are attributed to agriculture. This results from the estimates of point source loads, urban NPS loads and background loads being larger than the observed load. In the case of phosphate and nitrate this may be acceptable to a degree as these nutrients are removed naturally from the system and as such what is recorded as coming out of the system could be less than what is estimated to go into the system. It is less likely for salinity, which is not used by plants, although some salts may be stored in the soil zone for a period of time before being washed out during wetter periods. The negative loads for salinity to some degree reflect the uncertainty in the assumptions and the results, particularly with regards to the natural levels of salinity.

Given the variability in the data and the amount of infilling and assumptions made to prepare the data, it is expected that this uncertainty is very high, particularly at the monthly level, and should be taken into account when considering the results. For this reason any results from this First Order Estimate are exactly that, a very crude first order estimate intended to identify trends or areas of concerns in regard to net ANPS rather than come up with specific values and loading functions for different types of agriculture. Despite this uncertainty, and the problem of negative loads, it is possible to conclude that agriculture (in its broadest sense) does appear to have a major impact on the observed pollution loads in South African rivers. This impact, however, varies greatly between sub-catchments and a more detailed discussion of the results in each catchment follows.

4.1 Breede Catchment

Agriculture in the Breede Catchment appears to have a very significant impact on salinity and nitrogen loads. In all sub-catchments agriculture is responsible for between 60% and 75% of the incremental observed mean annual salinity load. The highest net ANPS salinity load is in the Kogmanskloof sub-catchment followed by the Riversonderend sub-catchment. Due to the fact that there is more agricultural land in the Riversonderend sub-catchment, however, the unit area load and the unit rainfall load are much higher in the Kogmanskloof, Vink and Poesjenels sub-catchments. This is despite a much higher assumed background salinity load in these sub-catchments. The net ANPS unit area load of between 1000kg/ha/a and 1300kg/ha/a is very high and is most likely due to the underlying shale and the disturbance of these through agricultural activities. The lowest net ANPS unit area load is in the Riversonderend sub-catchment. This may be due to the predominance of dry-land agriculture (predominantly wheat) in this sub-catchment, whereas the other sub-catchments tend to be dominated by the irrigation of vines and stone fruit orchards.

There appears to be two seasonal peaks in the salinity loads. The first occurs in around March and coincides with the arrival of the first rains. The second and much higher peak occurs in June and July when there is the greatest rainfall and run-off.

The net ANPS nitrogen load also appears to be a significant issue in the Breede, but unlike salinity, the two most affected catchments, in terms of total load, unit area and unit rainfall load, are the Hex and the Ceres sub-catchments. The Hex has the highest net ANPS nitrogen load (7kg/ha/a) and this could be due to the presence of predominantly table grapes under irrigation in this sub-catchment. The highest nitrogen loads tend to occur during the winter when there is the greatest amount of wash-off due to the winter rains which removes the nutrients accumulated in the soil as a result of fertilizers applied during the summer.

Agriculture, on the other hand, appears to be insignificant in terms of Phosphate loading in the Breede River. The mean annual net ANPS phosphate loads are all negative or close to zero. This implies that the observed phosphate loads are dominated by point sources and urban wash-off or the natural removal of phosphate, and not by agriculture. This hypothesis is supported by the fact that the most negative mean annual net ANPS phosphate load occurs in the Ceres catchment, which has the greatest urban area and the highest point source discharge. The sub-catchments with no urban areas, such as the Vink and the Poesjenels record close to zero net ANPS phosphate load, despite having the highest net ANPS salinity load.

The conclusion that nitrogen NPS pollution is of greater concern than phosphorus NPS pollution in catchments in the Western Cape such as the Breede, is supported by the findings of Annandale and du Preez (2004) who presented figures for the amount of nutrients added through fertilizers to a field near Malmesbury and the amount of nutrients removed when the crop is harvested. Based on their values it was found that on average, for the period 1991 to 1994, nitrogen was over applied by between 9 kg/ha/a and 57 kg/ha/a, depending on the tillage practice and application rate, while phosphate was under applied by between 2 kg/ha/a and 5 kg/ha/a.

4.2 Middle Vaal Catchment

As with the results from the Breede sub-catchments, the presence of negative monthly TDS loads is an indication of the uncertainty of the results at the monthly level. The results from the Rhenoster sub-catchment, which has a very low mean annual net ANPS unit salinity load and percentage of salinity load assigned to agriculture, are also suspect. The difficulty in this sub-catchment was the very low flows recorded at the gauge C7H006 where no flow was recorded during certain months for the entire period of study. While it is anticipated that flow would be low during this period, it is also probable that it was an error due to the concerns that the gauge is too wide to accurately measure low flows (DWAF, 1997).

Despite these concerns, agriculture does have some influence on the observed salinity load, but this is much less than in the Breede. The most impacted sub-catchment appears to be the Vet, i.e. below the Allermanskraal and Erfenis Dams, both in terms of net ANPS unit area and unit rainfall load. This may well be due to the high level of irrigation in this sub-catchment, but it is more likely due to an under-estimation of the impact that mines and quarries, which are most numerous in this sub-catchment, have on the salinity load. Herold *et al.* (1997) concluded that irrigation return flows in the lower Vet sub-catchment actually helped to dilute the pollution in the lower Sand and Vet Rivers as a result of the mining activity in the area. They estimated that the OFS Goldfields mines in this area contributed about 16000 t/a to salinity load, but that this could be as high as 59000 t/a in wet years. If this is taken into consideration then the net ANPS load would be reduced from 28000 t/a to about 12000 t/a or 30kg/ha/a.

The net ANPS unit rainfall load in the Erfenis sub-catchment is also relatively high, but this may be due to the low recorded rainfall as the unit area load is similar to that of the other sub-catchments. In general, however, agriculture appears to have much less of an influence in terms of mean annual salinity load in the Middle Vaal, than in the Breede. As a percentage of the total salinity load, agriculture, at between 60% and 70%, is similar to that in the Breede. There also appears to be two seasonal peaks in the net ANPS load in November and March, which coincides with the start of the rainy season and the period of greatest rainfall.

In terms of nutrients, the contribution of agriculture does not appear to be a major concern due to the dominance of point sources in most of these catchments, which result in negative net ANPS nutrient loads. Supporting this hypothesis is the fact that the catchments with the greatest amount of point source pollution, i.e. the Vals and the Vet also have the most negative net ANPS nutrient loads. Unlike the Breede, the trends for both phosphate and nitrogen loads are similar. The only sub-catchment to show a positive net ANPS phosphate and nitrogen load is the Erfenis sub-catchment, despite containing the Winburg WWTW, while the Koppies Dam sub-catchment has a positive net ANPS nitrogen load and the Rhenoster has a positive net ANPS phosphate load.

In terms of the top-down estimate of the potential nutrient pollution based on the values for fertilizer application and nutrient removal through harvesting collected by Annandale and du Preez (2004), phosphate pollution is a concern in this part of the country and not nitrogen. Based on average figures for the period 1991 to 1995, for fields near Bethlehem and Bloemfontein, nitrogen removal exceeds the application rate by between 4.5 kg/ha/a and 9.7 kg/ha/a. Phosphate application, however, exceeds phosphate removal through harvesting by between 4.4 kg/ha/a and 6.5 kg/ha/a.

4.3 Mgeni Catchment

The first observation from these results is that the net ANPS load from the Mpendle catchment is zero. This makes sense as the gauge for this sub-catchment (U2H013) was identified as the least impacted gauge in the drainage region and is therefore used to estimate the background or naturally occurring concentration throughout the catchment. While gauge U2H013, may be the "least impacted" gauge, the Mpendle sub-catchment is by no means completely unimpacted, as 26% of the land cover in this sub-catchment is classified as agriculture. Due to the high rural population in KwaZulu-Natal it is also likely that the actual area used for agricultural purposes, including the grazing of livestock is much larger. In addition, there is the possibility of dense rural settlements in this area, that are not recorded accurately on the NLCD. These factors will all tend to increase the pollution load at U2H013 which implies that the background concentration is actually much less than that observed at U2H013. In all the sub-catchments, except the Nagel sub-catchment, the percentage salinity load assigned to background concentrations is much higher than in either the Middle Vaal or the Breede. In order to improve the First Order Estimate in the Mgeni it will be necessary to review the estimated background concentrations, as it appears that this assumption makes a significant difference to the results.

Despite these concerns there are a number of provisional conclusions that can be drawn from the calculated net ANPS loads. The most impacted sub-catchment in terms of mean annual net ANPS unit area salinity load is the Nagel sub-catchment at 89 kg/ha/a. This could be as a result of the predominance of sugarcane and subsistence agriculture in this catchment or it could be due to the fact that the presence of the sugarcane, which is known to have a major streamflow reducing ability, has resulted in a very low incremental catchment run-off which has resulted in a relatively low estimated background load. This latter possibility is supported by the fact that both the Henley and the New Hanover sub-catchments have net ANPS unit area salinity loads around 25 kg/ha/a and yet are also dominated by subsistence farming and sugarcane, respectively.

The net ANPS unit area salinity load in the Lions sub-catchment (45 kg/ha/a) corresponds well to that observed by Archibald and Warwick (1987) of 49 kg/ha/a in the Lions, Mpendle and Karkloof sub-catchments. The unit area loads do not, however, correspond as well for the other two sub-catchments. Again this raises concerns about using U2H013 as a reference gauge for estimating the background loads.

As with the other catchments, negative net ANPS nutrient loads are calculated in the sub-catchments with point sources (Henley, New Hanover and Nagel). The possibility of recording a negative load by not including the natural removal of nutrients as discussed earlier is even more likely in the Mgeni sub-catchments given the relatively high estimated background loads.

In terms of nutrients, agricultural appears to have more of an impact on nitrogen load in the Mgeni than in the Middle Vaal, but much less so than in the Breede. The most impacted sub-catchment (1.13 kg/ha/a) is the Henley sub-catchment. This is most likely due to the high level of subsistence farming and corresponding rural settlements in this sub-catchment. The greatest phosphate net ANPS unit area load (0.12 kg/ha/a) is in the Nagel sub-catchment. This area was also identified as having the highest potential phosphate yield (up to 8.5kg/ha/a) by Kiensel *et al.*(1997) due to the large number of feedlots.

The greatest net ANPS load is recorded during the summer months, when there is the most rainfall and run-off. There does not appear to be a major "first flush" impact at the start of the wet season.

5 CONCLUSIONS

In general this project succeeded in its aims to review the available methods of assessing agricultural non-point source pollution loads, identifying pilot catchments, and collecting and evaluating the required data. It was possible to calculate the net agricultural NPS loads in the selected pilot catchments at a sub-annual level and make some initial findings on a First Order Estimate of the contribution that agriculture, in its broadest definition, makes to non-point source pollution in South African rivers.

It was, however, found that the readily available data was not adequate to support the selected bottom-up method. This introduced a high degree of uncertainty into the results and for this reason it was not possible to get more than a very crude First Order Estimate. It was also very difficult to come to any conclusions on the contribution that specific types of agriculture make other than a general feeling for the properties of a sub-catchment that may or may not result in a significant impact. Despite these difficulties a number of general conclusions can be drawn from this study and these conclusions are drawn from both the results of the First Order Estimate as well as the difficulties encountered in trying to calculate the First Order Estimate:

- The First Order Estimate calculated using a bottom-up approach is just that, a very simple, crude First Order Estimate of agriculture in its broadest sense. A more reliable Estimate will only be achieved through a more detailed study of individual catchments or the establishment of detailed water quality catchment modelling.
- While in theory South Africa has a relatively rich supply of readily available data on pollution sources and water quality, when pushed this data was often found to be lacking and inadequate for determining the sources of pollution and the relative contributions from these sources.

- The estimation of the contribution of agriculture to nutrient loads is complicated by the natural removal of nutrients. In many cases the impact of agriculture is masked, in a bottom-up calculation, by the return flows from wastewater treatment works and urban run-off. This results in a negative net ANPS nutrient load.
- The estimation of background and urban non-point source pollution loads is highly subjective as there has been insufficient work done in these areas, and the assumptions made for these loads makes a significant difference to the calculated net ANPS. The combining of observed monthly loads with lumped averages and estimates also leads to uncertainties and the calculation of negative loads, particularly at a monthly level.
- While the infilling of water quality samples did make a difference to the calculated in-stream loads, this difference is likely to be much smaller than the errors in the raw data and assumptions made of other pollution sources. For this reason, additional First Order Estimates could be made simply by using mean sampled water quality variables and annual estimates of point source pollution loads, urban loading, etc. rather than going to the added complexity of trying to calculate it on a sub-annual level.
- Agriculture appears to have a significant impact on salinity loads in all three pilot catchments, but is greatest in the Breede. This may be due to the high percentage of irrigation, but is also heavily influenced by the local geology.
- Agriculture does appear to have a significant impact on particularly nitrogen NPS loads in sub-catchments dominated by high value table grapes (Hex) and subsistence farming (Henley). In both cases, however, this may be due to relatively dense rural settlements in these catchments.
- In general, salinity levels are dominated by agriculture, while in catchments with known point sources the nutrient levels are generally more dependent on these than on agriculture.
- Impacts on a monthly level can be far greater than at the annual level, but the added level of complexity increases the uncertainty in the results and tends rather to confuse the issue than to clarify it.
- The net ANPS load, particularly for salinity, is greatest during the wet season and in some cases (Breede) there appears to be a "first flush" impact at the start of the wet season.
- The choice of period over which the net ANPS is calculated makes a significant difference to the results. It appears that agriculture has a greater impact in terms of unit area load during wetter periods.

6 RECOMMENDATIONS

Based on the above discussion and conclusions, the following recommendations are made:

- The monitoring of known point sources of pollution such as wastewater treatment works is crucial for determining the impact of agriculture on non-point source pollution and is essential to any proposed system for regulating the water quality of South African rivers. This project found the available data on known point sources, in the form of the POLMON database to be in a very poor state. It is imperative that DWAF reinstates this database as part of the WMS process in order to improve the state of available data on known point sources of pollution.
- The WRC must encourage continuing work to determine natural background water quality conditions and run-off loads associated with particular land-use types to assist in the future calculation of the impacts of non-point sources.
- The modelling of water quality issues in many of South Africa's important agricultural catchments must be encouraged as this will be the best way of not only getting a more accurate First Order Estimate, but will also allow for the simulation of the impacts of various management practices designed to reduce the impact of agricultural NPS pollution.
- More detailed studies into the pollution sources in significant catchments must be commissioned such as those done for the *Mgeni Catchment Water Quality Management Plan*. Catchments with known salinity and nutrient problems should be the initial focus.
- Agriculture does have a major impact on water quality, and farmers must be made aware of the impact that their activities could have on pollution levels and must be encouraged to take action to reduce these impacts, particularly in high risk catchments.

In the USA, a bottom-up approach is often used to write the Total Maximum Daily Load (TMDL) (MacMillan, 1999), which is used to help regulate water quality and identify major polluters. This works well in the US, where there is a high degree of monitoring of point sources and modelling of significant catchments. In South Africa, DWAF should strive towards developing a similar system, which will motivate for the improvement of the monitoring of major polluters, the availability of data on water quality concerns and the modelling of significant catchments. The ability to use a system of this nature to implement pollution charges could provide the financial incentives necessary to improve the state of pollution monitoring and mitigation practices by agriculture and other sectors to improve the health of South African rivers.

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